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Maintained Hand Function and Forearm Bone Health 14 Months After an In-Home Virtual-Reality Videogame Hand Telerehabilitation Intervention in an Adolescent With Hemiplegic Cerebral Palsy

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Abstract

Virtual reality videogames can be used to motivate rehabilitation, and telerehabilitation can be used to improve access to rehabilitation. These uses of technology to improve health outcomes are a burgeoning area of rehabilitation research. So far, there is a lack of reports of long-term outcomes of these types of interventions. The authors report a 15-year-old boy with hemiplegic

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Declaration of Conflicting Interests

The authors declared the following potential conflict of interest (eg, a financial relationship with the commercial organizations or products discussed in this article): The first and senior authors have applied for a patent on the technology described in this article.

Ethical Approval

This study was approved by the Indiana University School of Medicine Institutional Review Board, IRB 02-0710-26.

Author Contributions

MRG generated the first draft to final drafts and developed and was the principle investigator on the study. SJW designed the bone evaluation protocol, performed the bone tests and wrote that section of the article, and gave input on drafts of the article. EF provided advice to MRG and the 2 occupational therapists, wrote the occupational therapy section of the article, compiled the table, and reviewed drafts of the article. JY and BS helped design the occupational therapy evaluation protocol, performed the occupational therapy evaluations, gave input on the occupational therapy section, and reviewed drafts of the article. BR provided ongoing tech support during the study, interacted with the subject to tailor the telerehabilitation to him, performed analysis of the remotely monitored data, and reviewed the technological portions of the article. GCB is the founder of the Rutgers TeleRehabilitation Institute, and has developed the technology described in the article; he supervised and BR and other Rutgers students in their work. He also helped develop the entire study, wrote the technology sections, and reviewed and edited the final draft.

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cerebral palsy and epilepsy because of presumed perinatal stroke who improved his plegic hand function and increased his plegic forearm bone health during a 14-month virtual reality videogame hand telerehabilitation intervention. A total of 14 months after the intervention ended, repeat evaluation demonstrated maintenance of both increased hand function and forearm bone health. The implications of this work for the future of rehabilitation in children with neurological disabilities are discussed in this article.

Keywords

cerebral palsy; telerehabilitation; virtual reality

Key outcomes of rehabilitation interventions include changes in function, changes in health, and maintenance of those changes after the intervention ends. Technology can be used to promote rehabilitation by incorporating virtual reality, videogames, telerehabilitation that can be delivered to patients far from rehabilitation centers, and remote monitoring of compliance and change in function. We previously reported improved outcomes in hand function and forearm bone health in 3 adolescents with severe hemiplegic cerebral palsy after 3 and 10 months of a remotely monitored in-home virtual reality videogame hand telerehabilitation intervention.[1,2] One of those subjects continued for a total of 14 months of telerehabilitation. We report his maintained gains in hand function and forearm bone health at reevaluation 14 months postintervention.

Case Report

Our subject is a 15-year-old boy with presumed perinatal stroke and epilepsy. He came to neurological attention at the age of 6 months when he developed infantile spasms, was noted to have abnormal early hand preference, and was found to have a large left middle cerebral artery stroke on magnetic resonance imaging (MRI), which was presumed to have occurred in the perinatal period. He recovered from the infantile spasms and had an excellent cognitive outcome, but did have continued severe right hemiplegia and epilepsy that was well controlled on oxcarbazepine. His outcome at the age of 9 years has been described previously.[3] His hemiplegia was treated with intensive occupational therapy and multiple orthopedic surgeries, including multiple tendon transfers on the right arm and extensor pollicis longus oppensplasty. He also received metacarpophalangeal capsulodesis, metacarpophalangeal joint fusion, and first web space Z-plasty on the thumb. He had tried botulinum toxin injections, but did not find it helpful. He had received intensive physical and occupational therapy in early childhood, but this decreased as he grew older. His in-school occupational therapy was only about 15 minutes per week, and he was discharged from school therapy by fifth grade. His family’s insurance covered some occupational therapy and he received outpatient occupational therapy twice a week for 20 minutes a session on and off through his school and early teenage years. He was able to pick up lightweight bath toys with his plegic hand by the age of 7 years, but found this unsatisfying and “babyish” and as a result became more resistant to attending occupational therapy by the age of 9 years. He regressed over the next several years and lost the ability to open and close his hand at will.

He agreed to enter our pilot study of in-home remotely monitored hand telerehabilitation with virtual reality videogames when he was 13 years.

Methods

The telerehabilitation system incorporated a 5DT 5 Ultra Glove (Fifth Dimension Technologies, Persequor Park, South Africa), a 26-inch high-definition TV, a keyboard, and a PlayStation3 game console programmed with custom rehabilitation games. The home system was networked with both Riley Hospital and Rutgers University through a digital subscriber line (DSL) modem/router. Exercise time was measured remotely. This system has been described in detail in previous publications (see Figure 1).[1,2,4]

Hand function was measured using grip strength and the Jebsen test of hand function.[5] From the initial installation to August 2010, a total of 5 evaluation sessions were conducted using grip strength and the Jebsen hand function test as outcome measures. Time span from baseline evaluation in March 2008 to last follow-up evaluation in August 2010 was 29 months. A 1-tailed Student *t* test was used to assess outcome measures. He did not receive botulinum toxin injections to the plegic arm in the 8 months before study onset. He did not receive additional conventional occupational therapy during or after the intervention.

Forearm bone health was assessed bilaterally using dual-energy x-ray absorptiometry and peripheral quantitative computed tomography as previously described.[1] Dual-energy x-ray absorptiometry was used to determine total distal radius bone mineral content (g), whereas peripheral quantitative computed tomography was used to determine ultradistal radius trabecular bone mineral content (mg/mm) in a 2-mm thick tomographic slice at a distance of 4% of total bone length proximal to its distal end.

Results

Exercise Time

Baseline evaluations were performed on March 5, 2008, and his first day of hand exercises was March 23, 2008. During the first 12 months of the intervention, he exercised an average of 2.6 sessions a week for an average of 21 minutes a session, with total exercise time of 48 hours and 51 minutes. Because of technical issues, we do not have a comprehensive record of exercise time during the last 2 months of the intervention. He was evaluated 10 months into the intervention on December 30, 2008, and his end-of-intervention evaluations were performed June 10, 2009. Postintervention bone evaluations were performed August 2, 2010, and postintervention occupational therapy evaluations were performed August 10, 2010.

Hand Function

In the plegic hand, grip strength as measured with a Jamar dynamometer improved from 4 pounds to 9 pounds between baseline testing and August 2010, representing a 225%increase (see Table 1).

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At baseline testing in March 2008, the subject was unable to accomplish 3 of the 7 Jebsen timed subtests (writing, stacking checkers, and lifting large heavy objects), but was able to accomplish these tasks in follow-up testing. In general, the improvements from baseline to June 2009 scores ($P = .0020$) and baseline to August 2010 scores ($P = .0168$) for the above 3 subtests were statistically significant.

For the remaining 4 Jebsen subtests including simulated page turning, picking up small objects, simulated feeding, and lifting large light objects, the subject's improved scores were not statistically significant ($P = .4132$) from baseline to June 2009 when the system was removed. However, the time improvements for these 4 subtests were statistically significant from baseline to August 2010 ($P = .0267$), indicating that the changes in hand function in these 4 areas continued to progress even after the videogame training was discontinued (mean decrease in time of 15.5 seconds from June 2009 to August 2010).

Forearm Bone Health—At study entry, the subject had substantially inferior bone health in his paretic upper extremity as indicated by 40.5% lower total distal radius bone mineral content, and 51.8% lower ultradistal radius trabecular bone mineral content compared with his nonparetic upper extremity. After 14 months of telerehabilitation, bone health in the paretic upper extremity had improved, as indicated by a reduction of paretic-to-nonparetic differences in total distal radius bone mineral content and ultra-distal radius trabecular bone mineral content of 33.5% and 37.2%, respectively. These improvements were maintained for at least 14 months following the completion of telerehabilitation with paretic-to-nonparetic differences in total distal radius bone mineral content, and ultradistal radius trabecular bone mineral content at this time point being 33.3% and 35.7%, respectively.

Discussion

In the population of children with neurological disabilities, there has been a chronic need for rehabilitation that is motivating and accessible with a lasting effect. The ideal rehabilitation promotes both function and long-term health. Technology seems to offer promising approaches. Our pilot work suggests that part of the long-term solution will be in-home remotely monitored videogame-based telerehabiltation.[1,2]

Other groups have used virtual reality to motivate rehabilitation in children. Several studies of children with cerebral palsy[6–8] have found that motivation plays an important role in rehabilitation. One study found that children with cerebral palsy had significantly better reaction and movement times when they received praise than when they did not.[9] Rehabilitation that incorporates play also aids in motivation.[10] Several small studies have found that this population seems to respond well to rehabilitation that incorporates virtual reality, in part because it allows them to quickly achieve motor tasks in the virtual world they cannot in the regular world, and the quick success motivates them to keep exercising.[6,11] Occupational therapists and physicians have begun to make use of off-the-shelf videogame systems including the Wii ("Wiihabilitation") to motivate patient participation in rehabilitation.[12] However, the difficulty of many Wiihabilitation games, which are designed for healthy individuals, may render them inappropriate for use by some disabled children, and may lead to loss of patient motivation. Our games were customized to the patient; he set his own baseline at the beginning of each session, then had to repeat exercises he could do at baseline to earn points. He was able to earn high scores from the beginning and his mother reported hearing him cheer from his bedroom when he got “bonus points.” Motivation also may have contributed to the maintenance of hand function and continued improvement in bone health after the intervention stopped. Our subject was so pleased with his increased function that he started to use it more, enjoying the fact he could carry light grocery bags and other light items in his plegic hand.

Access to rehabilitation has been an ongoing problem for the pediatric neurology population, particularly for children who live in small towns or rural areas far from large rehabilitation centers. Many children with hemiplegic cerebral palsy have limited or no access to hand rehabilitation after the age of 3 years. In Indiana, the state’s First Steps program provides in-home occupational therapy once a week, usually for 30 to 60 minutes, until the child turns 3 years.[13] Most states have similar programs.[14–16] After that, children receive occupational therapy in school, sometimes for 20 minutes a month or less, even for children with severe hemiplegia (M. R. Golomb, personal communications, 2006–2010). Patients whose families have private insurance may be able to obtain additional therapies, but in most cases families must pay out-of-pocket for additional interventions. When a child turns 18 years, rehabilitation is dependent on insurance status and can be difficult to obtain.[17,18] School and work demands also limit patients’ abilities to access hand rehabilitation multiple times a week. Our subject lived in a small town, but because our system was installed in his bedroom (see Figure 1), it was easily accessible after school and on weekends.

Measurements of bone health are not always included as outcome measures in rehabilitation studies. However, we feel it is an important outcome measurement in children with neurological diseases that limit movement, as movement is needed to promote bone growth, strength, and long-term health. For example, hemiplegic cerebral palsy may lead to delayed skeletal maturation on the plegic side. A study of 19 children with hemiplegic cerebral palsy found that bone mineral content was on average 26.5% lower in the plegic upper limb than the unaffected upper limb.[19] Limb disuse and anticonvulsant use both appear to contribute to osteopenia.[20] This osteopenia places these patients at risk for early, low-trauma fractures in plegic limbs.[20] Our patient had both chronic severe hemiplegia and chronic epilepsy. His improvement in forearm bone health is encouraging. His increased use of the plegic hand during and after the intervention was likely contributory, as the game itself did not involve weight-bearing exercises.

There are still multiple barriers to this type of intervention. The technology is new and still being perfected. In our original study,[1] we only enrolled subjects and families where we were able to obtain both assent from the subject and consent from the guardian. It is expensive because of both equipment and personnel costs. Our research team has been large. Limited funding and difficulty in obtaining continuing funding has limited our ability to develop new games and equipment and to enroll new subjects. Subjects’ social and familial issues have also limited our abilities to provide prolonged telerehabilitation and detailed follow-up on all 3 of the original subjects. Over time, our system lost its novelty for the subjects, and we sought ways to keep them engaged.

While our pilot work suggests that remotely monitored in-home hand telerehabilitation may have the potential to produce lasting changes in hand function and forearm bone health, clearly far more work is needed. We continue to seek funding to duplicate our findings in a larger cohort of adolescents with hemiplegic cerebral palsy, and in children and young adults with a wide range of neurological impairments. We feel this approach has the potential to promote rehabilitation not just in the hand, but also in any body part impaired by neurological illness.

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Figure 1.

A Rutgers engineering student adjusts the hand telerehabilitation system, which is installed in our subject’s bedroom. Note the sensor glove on his plegic right hand.

Table 1

Change in Function of the Plegic Right Hand Over Time

		Date	**Grip Strength in Pounds**	**Comments**
Grip (normal: 36–69 pounds; mean: 46 pounds)[21]				
	Baseline	3/5/2008	4	
		6/13/2008	5	
		12/30/2008	4	
	System removed	6/10/2009	6	
	Follow-up	8/10/2010	9	
		Date	Time in Seconds	Comments
Jebsen				
	Writing	3/5/2008	Unable	
		6/13/2008	Unable	
		12/30/2008	Unable	
		6/13/2009	24	Used good hand as assist
		8/10/2010	28	Held plegic hand closed with nonplegic hand
	Simulated page turning	3/5/2008	70	
		6/13/2008	45	
		12/30/2008	66	Picked up 2 cards at once; all cards stayed on table; slid cards to edge of table
		6/13/2009	39	Slid cards to edge of table this time
		8/10/2010	55	One card fell off table; slid cards to the edge of table each time
	Pick-up small common objects	3/5/2008	101	
		6/13/2008	71	
		12/30/2008	118	Dropped 2 pennies and 1 paper clip
		6/13/2009	64	Dropped 2 pennies and 2 paper clips; only able to put bottle caps in can
		8/10/2010	48	Dropped 2 pennies and 2 paper clips
	Simulated feeding	3/5/2008	77	
		6/13/2008	158	

	Date	Grip Strength in Pounds	Comments
	12/30/2008	185	Able to get all 5 beans one at a time on spoon and lifted into can; used nonplegic hand to assist in adjusting spoon in plegic hand
	6/13/2009	158	Three beans in can; used nonplegic hand to assist in adjusting spoon in plegic hand
	8/10/2010	65	Used nonplegic hand to assist in adjusting spoon in plegic hand
Stacking checkers	3/5/2008	Unable	
	6/13/2008	46	
	12/30/2008	135	Placed all on board but unable to stack
	6/13/2009	44	Unable to stack
	8/10/2010	108	Stacked 1 checker out of 4
Lifting large, light objects	3/5/2008	85	
	6/13/2008	51	
	12/30/2008	58	Three cans on board; used nonplegic hand to assist with release; 2 cans fell to floor
	6/13/2009	46	Used nonplegic hand to assist with release; 1 can fell to floor
	8/10/2010	77	Used nonplegic hand to assist with release
Lifting large, heavy objects	3/5/2008	Unable	
	6/13/2008	49	
	12/30/2008	28	Able to pick up all 5 cans and release on board without assistance from nonplegic hand
	6/13/2009	37	Used nonplegic hand to assist in release of can
	8/10/2010	43	Used nonplegic hand to assist in release of can

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